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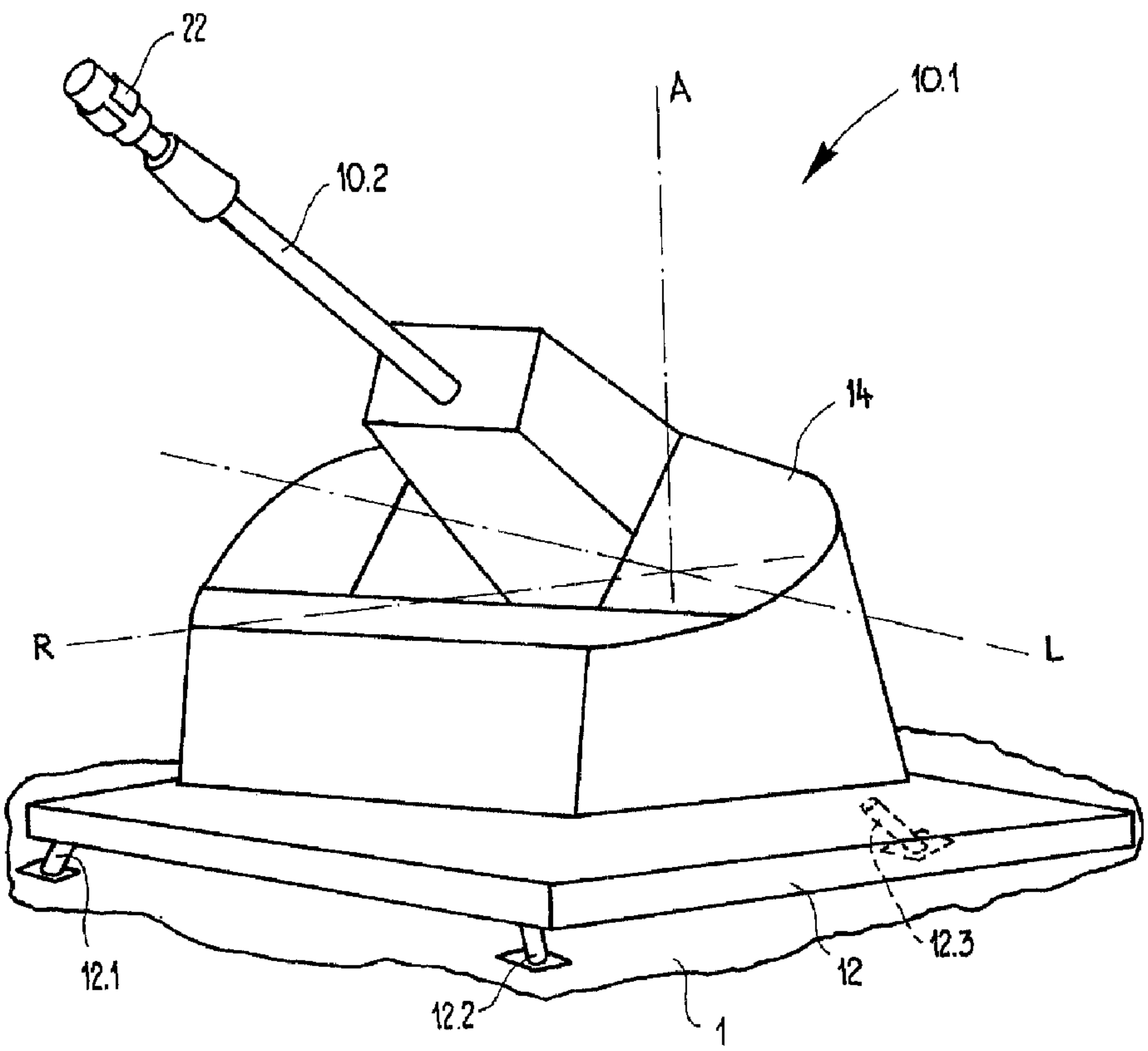
(54) Titre : METHODE ET DISPOSITIF DE COMPENSATION DES ERREURS DE TIR ET CALCULATEUR POUR SYSTEME D'ARME

(54) Title: METHOD AND DEVICE FOR COMPENSATING FIRING ERRORS AND SYSTEM COMPUTER FOR WEAPON SYSTEM



(57) Abrégé/Abstract:
A method and a device (20) are described for compensating firing errors of a gun having a weapon barrel (10.2). Firing errors, which are caused by static gun geometry errors, which influence the position of the weapon barrel (10.2) during aiming of the

(57) Abrégé(suite)/Abstract(continued):
weapon barrel (10.2) at aiming values, are compensated. For this purpose, the weapon barrel (10.2) is brought into measurement positions in steps by rotation around an axis. Using suitable devices of a measurement facility, an intended value, which describes the intended position of the weapon barrel (10.2), and an actual value, which describes the actual position of the weapon barrel (10.2), are detected at each measurement position. A difference between the actual value and the intended value, defined as an error value, is then calculated. Correction values are established from multiple error values of the measurement positions and the correction values are taken into consideration during later aiming of the weapon barrel (10.2). The method and the device (20) are used for a weapon system (10) which has a system computer (10.4) for calculating aiming values for aiming a weapon barrel (10.2) of a gun (10.1) of the weapon system (10); the system computer (10.4) has a data input (24) for data which is made available, this data being intended for the purpose of being taken into consideration during the calculation of the aiming values, in order to compensate aiming errors, which are caused by static gun geometry errors and which influence the position of the weapon barrel (10.2).

Abstract of the Disclosure

A method and a device (20) are described for compensating firing errors of a gun having a weapon barrel (10.2). Firing errors, which are caused by static gun geometry errors, which influence the position of the weapon barrel (10.2) during aiming of the weapon barrel (10.2) at aiming values, are compensated. For this purpose, the weapon barrel (10.2) is brought into measurement positions in steps by rotation around an axis. Using suitable devices of a measurement facility, an intended value, which describes the intended position of the weapon barrel (10.2), and an actual value, which describes the actual position of the weapon barrel (10.2), are detected at each measurement position. A difference between the actual value and the intended value, defined as an error value, is then calculated. Correction values are established from multiple error values of the measurement positions and the correction values are taken into consideration during later aiming of the weapon barrel (10.2). The method and the device (20) are used for a weapon system (10) which has a system computer (10.4) for calculating aiming values for aiming a weapon barrel (10.2) of a gun (10.1) of the weapon system (10); the system computer (10.4) has a data input (24) for data which is made available, this data being intended for the purpose of being taken into consideration during the calculation of the aiming values, in order to compensate aiming errors, which are caused by static gun geometry errors and which influence the position of the weapon barrel (10.2).

Method and device for compensating firing errors and system computer for weapon system

The present invention relates to a method and a device for compensating firing errors of a gun, having a weapon barrel, of a weapon system, which are caused by static gun geometry errors, according to the preambles of Claims 1 and 12, respectively, and a system computer for a weapon system according to the preamble of Claim 17.

In principle, the present invention relates to all possible static gun geometry errors and their compensation.

Guns comprise numerous individual parts which are connected rigidly or movably to one another. The individual parts can never be produced with precise dimensional accuracy, but rather only with certain manufacturing tolerances and/or deviations from the theoretically determined dimensions, and deviations, within the fixed assembly tolerances, from the intended mutual positions also result during assembly. The totality of the deviations has the consequence that every gun has deviations from its ideal geometry, which are referred to as gun geometry errors. Such gun geometry errors are composed of numerous types of errors. For example, gun geometry errors are manifested in that azimuth α of the weapon barrel in the zero position, as it is indicated by an azimuth display of the gun, is not equal to 0° in actuality, but deviates from 0° by a slight angle $\Delta\alpha$. Correspondingly, elevation λ of the weapon barrel in its zero position may not have the value 0° indicated by the elevation display of the gun, but rather may deviate by a slight angle $\Delta\lambda$ from 0°. In certain cases, $\Delta\alpha$ and $\Delta\lambda$ may be equal to zero, but only if different gun geometry errors compensate one another.

The manufacturing tolerances may be equal or approximately equal for identical individual parts of a series of guns, if such individual parts are always produced on the same machines, using non-wearing or precisely adjustable tools and in identical external conditions, such as temperature conditions. However, after assembly the gun geometry errors will be different from gun to gun.

The problem is worsened in that the gun geometry errors, particularly the angular errors, are not constant, but rather change for different reasons. For movable individual parts, such changes are primarily the consequence of wear; therefore, they increase over the course of time. The change of the errors is, however, also connected to the existing environmental conditions, such as the air and gun temperatures; they may therefore alternately increase and decrease.

A further complication arises in that the gun geometry errors are also influenced by the respective positions of the individual parts, since the mechanical loads and therefore the deformations of the individual parts are partially dependent on position.

Finally, the gun geometry errors which manifest in a specific position of the weapon barrel and at a specific time may also be a function of the rotational direction in which the weapon barrel is brought into this specific position.

The gun geometry errors characterize the individual guns and therefore represent actual gun parameters. Firing errors and/or a reduction of the accuracy performance of the gun result as a consequence of the gun geometry errors, particularly as a consequence of the angular errors. Due to the large distances between the muzzle of the weapon barrel and the targets which are to be hit by the projectiles fired from the weapon barrel, even slight angular deviations of the weapon barrel cause significant deviations of the projectiles from the targets to be combated.

If the gun geometry errors and/or gun parameters are known, then the firing errors which they cause may be compensated, in that the gun parameters may be taken into consideration in addition to other data by the software of a computer assigned to the gun during the determination of the aiming values. The concept of a computer assigned to the gun is to be understood to mean a gun computer and/or a computer of a fire control device. Other data which is to be taken into consideration by the computer particularly includes target data, which describes the location and the movement of the target, meteorology data, which describes the respective meteorological conditions, v_0 data, which relates to the deviation of the actual muzzle velocity from a theoretically determined muscle velocity, and possibly shell data, which characterizes the respective shells fired.

The determination of the gun geometry errors and/or gun parameters, their evaluation to obtain correction functions, and the implementation of the correction functions in the software of the computer must be performed before the gun is put into operation, and must be done individually for each gun.

The previously known methods for measuring the gun parameters have numerous disadvantages. Not all types of gun geometry errors may be measured. The measurements cannot be performed in an automated way and therefore require a large amount of time; as a consequence, only a few measurements are made per measurement position of the weapon barrel, which has the consequence that random measurement errors cannot be eliminated. The measurements not only require a large amount of time, but also require a relatively large number of personnel, so that they are very costly. In addition, some of the measurement personnel are subjected to relatively great danger, since they must be located in the region of the weapon barrel muzzle to perform the measurements; for larger elevations and long weapon barrels, this means that measurement personnel must be lifted into the region of the weapon barrel muzzle using a lift device or measurements must be performed on a ladder.

The object of the present invention is therefore,

- to indicate a method for compensating firing errors of the type initially described which allows complete detection of the gun geometry errors and may be performed precisely, rapidly, using few personnel, and preferably automated;
- to suggest a device for performing this method; and
- to suggest a fire control computer and/or system computer for a weapon system, to which the novel device may be coupled.

According to the present invention, there is provided a method for compensating firing errors of a gun having a weapon barrel, caused by static gun geometry errors, which influence the position of the weapon barrel during aiming of the weapon barrel at aiming values,

- the weapon barrel is brought into measurement positions in steps by rotation around an axis,
- at each measurement position

- an intended value, which describes the intended position of the weapon barrel, and
- an actual value, which describes the actual position of the weapon barrel, are detected,
- a difference between the actual value and the intended value, defined as an error value, is calculated,

- correction values are established from multiple error values and
- the correction values are taken into consideration during later aiming of the weapon barrel.

According to the present invention, there is also provided a device for compensating firing errors of a gun having a weapon barrel, these firing errors being caused by static gun geometry errors, which influence the position of the weapon barrel during aiming of the weapon barrel at calculated aiming values, this device having a measurement facility for establishing actual values, which describes the position of the weapon barrel, the measurement facility having an optical-electronic gyroscopic measurement system on the weapon barrel, having a first measurement unit, in order to detect azimuth synchronization error and possibly perpendicular offset error.

According to the present invention, there is also provided a system computer of a weapon system for calculating aiming values for aiming a weapon barrel of a gun of the weapon system, characterized in that:

- the system computer has a data input for data representing correction values,
- the system computer calculates aiming values, based on said data representing correction values, compensating aiming errors caused by static gun geometry error which influence the position of the weapon barrel.

- All angular errors which are caused by static gun geometry errors may be detected and therefore compensated.
- Static gun geometry errors, which until now could only be determined imprecisely and at great cost, may now be measured precisely and may correspondingly be efficiently compensated.
- The use of a gyroscopic measurement system allows angular measurements to be performed without previously leveling the horizontal of the weapon.
- The use of an optical-electronic gyroscope, particularly a fiber-optic gyroscope, allows angular measurements to be performed whose precision, reliability, and reproducibility greatly exceeds the previously performable measurements and which provide significantly more detailed measurement results than those which could previously be achieved; in this way, much more precise compensations of the firing errors caused by the gun geometry are made possible.
- The measurements may be performed rapidly and automatically; the outlay in time and personnel for measuring a gun is low, which results in significant cost savings.
- The danger of accidents for persons taking part in the measurements may be greatly reduced.

Before the invention is described in more detail in the following, several basic concepts will be explained.

Although only azimuth synchronization error, elevation synchronization error, perpendicular offset error, wobble error, and squint error, as well as their compensation, are described in more detail in the following, the basic idea of the present invention is applicable to all gun geometry errors which occur.

The weapon barrel, whose position is influenced by the gun geometry errors, may be brought into various positions through back-and-forth pivoting or complete rotation, each position being defined by the corresponding azimuth, i.e., the corresponding lateral angle, and by the corresponding elevation, i.e., the corresponding vertical angle. A rotation around the vertical axis changes the azimuth and a rotation around the lateral axis changes the elevation. The vertical axis and the lateral axis are two axes of a spatial, preferably orthogonal, axis system, whose axes are defined in Table 1. In the framework of the present description, the azimuth is understood to be not the deviation from north, as in firing operation, but from a zero position.

Table 1
definition of the axes

L axis lateral axis	(theoretical) horizontal axis, around which the weapon barrel is pivotable; elevation λ is set in this way;
A axis vertical axis	(theoretical) vertical axis, around which the weapon barrel is pivotable; azimuth α is set in this way.
R axis longitudinal axis	(theoretical) horizontal axis of the weapon barrel in the tied down position, with azimuth $\alpha = 0$ and elevation $\lambda = 0$;

Firing errors occur because the actual position of the weapon barrel is not equal to its intended position. The intended position is defined by, among other things, the values for azimuth and elevation established by the fire control computer and/or system computer, but is not assumed due to static gun geometry errors. The angular error of the position of the weapon barrel which occurs, the gun geometry errors which cause it, and the primary causes of the gun geometry errors may be seen in Table 2. The angular errors, which manifest as azimuth errors and elevation errors, comprise the following five types of errors, which, however, are not independent of one another:

(1) azimuth synchronization error $\Delta\alpha 1$
(2) wobble error $\Delta\tau$

(3) elevation synchronization error $\Delta\lambda$

(4) perpendicular offset error $\Delta\alpha 2$

(5) squint error $\Delta\sigma$

Table 2

Angular errors of the position of the weapon barrel, gun geometry errors, and their causes

Angular errors	Gun geometry errors	Causes
Azimuth errors (lateral errors)	$\Delta\alpha1$ azimuth synchronization error	1. Eccentricity of the lateral pivot bearing 2. Out-of-round of the lateral pivot bearing 3. Variable tooth intervals in the crown gear of the lateral pivot unit 4. Coder error
	$\Delta\alpha2$ perpendicular offset error	5. Tilting of the elevation axis toward the horizontal 6. Non-orthogonality of barrel axis and elevation axis
	$\Delta\sigma$ squint error	7. Non-parallelism of barrel axis and line of sight
elevation errors (vertical errors)	$\Delta\lambda$ elevation synchronization error	8. Eccentricity of the vertical pivot bearing 9. Out-of-round of the vertical pivot bearing 10. Variable tooth intervals in the crown gear of the vertical pivot unit 11. Coder error 12. Backwards skipping of the gun with increasing elevation
	$\Delta\tau$	13. Elasticity of the structure
	$\Delta\sigma$ squint error	7. Non-parallelism of barrel axis and line of sight

In order to determine these partial errors, multiple measurements are performed. For an efficient procedure it is advantageous to perform the measurements in the course of three measurement procedures, since in each position of the weapon barrel, measurements are performed which relate to more than one type of error. Three measurement procedures, the partial errors, and the respective measurement devices used are shown in Table 3.

Table 3

Angular errors, measurement procedures, and measurement devices

Measurement procedure	relates to partial error		Measurement device
1	Azimuth synchronization error Wobble error	$\Delta\alpha 1$ $\Delta\tau$	Gyroscopic measurement device spirit level
2	Elevation synchronization error Perpendicular offset error	$\Delta\lambda$ $\Delta\alpha 2$	Gyroscopic measurement device Gyroscopic measurement device
3	Squint error	$\Delta\sigma$	Optical device (target telescope)

For compensating the firing errors, which are based on static gun geometry errors of a gun, in principle the procedure is as follows: an angular error which arises during movement of the weapon barrel around one of the rotational axes is determined. The weapon barrel is brought into a final position, which is also a measurement position, from a zero position in steps, by rotation in one rotational direction around the rotational axes described, via sequential measurement positions. The rotation is controlled by a computer. Using a suitable measurement unit of a measurement facility, after each step the actual angle around which the weapon barrel has rotated is determined; this angle is referred to as the actual value. Simultaneously, after each step the theoretical angle around which the weapon barrel is to have rotated, for example in accordance with information on a scale on the gun or on the assigned fire control computer and/or system computer, is determined; this angle is referred to as the intended value. The angular difference between the intended value and the actual value is then calculated for each measurement position; this difference is referred to as the error value. A correction value is established from the error value, which is implemented in the software of the fire control computer and/or system computer and is subsequently taken into consideration in the determination of the aiming values, i.e., the values for azimuth and elevation. The aiming values are primarily calculated using target data, i.e., data which describes positions and possible movements of a target to be combated, and using ballistics data. This primary calculation is corrected with the aid of the method according to the present invention.

In particular, the actual values may be represented as a function of the intended values to establish the correction values and may be prepared in such a way that the correction values may be determined therefrom. Such a preparation, in which correction values result from the measured angular errors, may be performed numerically and/or with tabular aids or mathematically or numerically/mathematically combined.

Preferably, for the numeric method, value pairs are stored in a table, a first value being the intended value and a second value being the actual value or the difference between the actual value and intended value in each value pair. The value pairs may also be considered as an empirical error curve. The table and/or the empirical error curve is then available during the calculation of aiming values in such a way that the calculation of each aiming value is performed in a corrected way, taking into consideration the corresponding values of the table and/or the empirical error curve.

Preferably, for the mathematical method, the error values are first represented in tabular form as a function of the intended angle and/or as an empirical error curve and then approximated by at least one mathematical function; i.e., the empirical error curve is either approximated over its entire course by one single mathematical error function or in each section by a mathematical partial error function, and thus as a whole by multiple mathematical partial error functions. The mathematical error function is then made available to the computer, which determines a correction function therefrom, which it takes into consideration during the calculation of the aiming values for the weapon barrel, i.e., the azimuth and the elevation.

The numerical method may be designed in such a way that the necessary precision for the compensation of the firing errors is ensured. However, as described below, the mathematical methods have the advantage that mathematical error functions may be analyzed simply, specifically using known mathematical methods; not only may the values for the compensation of the firing errors be obtained therefrom, but also insights into the influence of individual constructive conditions on the error functions; constructive improvements resulting therefrom serve, in the final analysis, to combat the firing errors caused by gun geometry at the root, in that the gun geometry errors are eliminated. The concept of constructive relates to both conceptual conditions, and to conditions relating to production and assembly.

To remove random measurement errors, it is advantageous to repeat the measurement procedure described above once or multiple times and to average the values obtained in tabular form. Alternatively, an average empirical error curve may be formed from all identically performed measurement procedures or a mathematical error function may be formed from each empirical error curve and an average mathematical error function may be formed from these functions or a correction function may be formed from each empirical error curve and an average correction function may be formed from all correction functions.

Preferably, for the measurements described above, the rotation of the weapon barrel is always in the same rotational direction; the error values obtained in this way are mono-directionally determined error values, which may be numerically or mathematically prepared. In particular, the empirical error curve and/or mathematical error function is a mono-directionally determined and/or mono-directional error curve and/or error function. The error values are, however, as described above, generally a function of, among other things, the rotational direction in which this rotation was performed. It is therefore advantageous to ______________________________ perform two measurements. For this purpose, the weapon barrel is rotated, around the same rotational axis, in one rotational direction for the first measurement and in the opposite rotational direction for the second measurement. The measurement positions of the first-directional rotation and the measurement positions of the second-directional rotation may correspond, but do not have to. During these rotations, first-directional and second-directional error values are established. If the deviations between the first-directional and the second-directional error values are small, then a direction-free error value may be established and prepared and/or analyzed further. In particular, an average direction-free empirical error curve may be established, from the first-directional empirical error curve and the second-directional empirical error curve, from which an average direction-free mathematical error function and, from this, an average direction-free correction function may be established, the correction function being taken into consideration in the calculation of the aiming values. Since, however, the influence of the rotational direction results in a systematic error component of the overall error values, both the first-directional error values and the second-directional error values are preferably prepared and/or analyzed separately.

Depending on the errors to be detected, as already described, various measurement devices are used. In particular, spirit levels, preferably electronic spirit levels, and gyroscopic measurement systems, preferably optical-electronic gyroscopic measurement systems, these being understood to include, for example, ring laser gyroscopes and fiber-optic gyroscopes, are used. The measurement devices must generally be calibrated after being mounted on the gun and/or on the weapon barrel, before beginning a measurement procedure. For the use of gyroscopic measurement systems, the continuously changing gyroscopic drift must also generally be detected and the values measured must be corrected in accordance with the gyroscopic drift. An example of the detection and consideration of the gyroscopic drift is described in European Patent Application 00126917.4.

The description above relates to establishing a correction function, which is based on detecting error values arising during the rotation of the weapon barrel around one of the axes. However, the weapon barrel is not rotated around only one axis, but around two non-coincident, generally orthogonal axes. The first axis is preferably vertical axis A and the second axis is preferably lateral axis L, azimuth α being set by rotation around vertical axis A and elevation λ being set by rotation around lateral axis L.

In the course of a first measurement procedure, azimuth synchronization error $\Delta\alpha 1$ and wobble error ΔT may be established.

Preferably, to detect azimuth synchronization error $\Delta\alpha 1$, azimuth α of the weapon barrel is changed in steps at an elevation of 0°. For the mathematical methods, the azimuth errors established in this way provide an azimuth error curve which is generally constituted so that it may be approximated by a sine function, a rotation of the weapon barrel by 360° corresponding to one or more periods of the sine function. A first measurement unit of the gyroscopic measurement system is used as a measurement device.

Preferably, wobble error ΔT is also detected within the first measurement procedure. For this purpose, the rotations of the weapon barrel performed to detect azimuth synchronization error $\Delta\alpha 1$ may be repeated. However, the actual azimuth and the intended azimuth and/or their difference are not detected and/or established. The actual angle of inclination of the weapon barrel axis to the horizontal is detected; this angle of inclination is referred to as the actual wobble angle and/or actual value. The theoretical angle of inclination, which is referred to as the intended wobble angle and/or intended value, is always zero in this case, since the measurement procedure is performed at an elevation of 0°. Therefore, the wobble movement during a rotation around vertical axis A is detected. However, it would also be possible to perform the measurement procedure at a constant angle of elevation which is not 0°; in such a case, the intended wobble angle would correspond to this constant, theoretical angle of elevation, and the actual wobble angle would correspond to the deviation of the actual angle of elevation from the theoretical angle of elevation. A spirit level, preferably an electronic spirit level, is used as a measurement system.

Elevation synchronization error $\Delta\lambda$ and perpendicular offset error $\Delta\alpha 2$ may be determined in the course of the second measurement procedure.

Preferably, elevation synchronization error $\Delta\lambda$ comprises two components, which may only be determined jointly.

Preferably, a first component of elevation synchronization error $\Delta\lambda$ is based - analogously to the azimuth synchronization error - on the fact that the respective actual angle of the weapon barrel does not correspond to the intended angle. A partial error curve and/or partial error function describing this component of elevation synchronization error $\Delta\lambda$ has the nature of a sine function, possibly having multiple angular frequencies.

Preferably, a further component of elevation synchronization error $\Delta\lambda$ is based on the fact that the torque applied to the gun carriage by the weight of the weapon barrel becomes lower with increasing elevation; this torque has the tendency to rotate the weapon barrel downward; in a tied down position, for example with azimuth 0° and low elevation, the gun would tend to tip forward. Due to the reduction of the torque with increasing elevation, the weapon barrel is pulled downward less, with the consequence that the gun tips forward less and/or, in comparison to the tied down position, tips backward. The partial error curve and/or partial error function which describes this component of the elevation synchronization error has the nature of a cosine curve subtracted from 1 with a single angular frequency.

Preferably, the measurements of the second measurement procedure, using which the elevation synchronization error is determined, run analogously to the measurement procedure using which the azimuth synchronization error is detected. For the mathematical method, they provide an error function like a sine function corresponding to the first component of elevation synchronization error, however, this sinusoidal function does not oscillate around a horizontal, but around the continuously rising curve of the cosine curve subtracted from 1, corresponding to the second component of the elevation synchronization error. The two partial error functions may be separated mathematically. Such a separation does not have to be performed to calculate the corresponding correction function, since only the result, specifically the correction of the overall elevation synchronization error, is significant. The partial error functions may, however, possibly be of interest, because they more clearly display errors of the gun construction, the temperature dependence of individual assemblies, the wear, and other things. A second measurement unit of the gyroscopic measurement system is used for the measurement.

Preferably, perpendicular offset error $\Delta\alpha 2$, which may also be established within the second measurement procedure, is based on the fact that elevation axis L and azimuth axis A are not, as desired, orthogonal to one another, and the weapon barrel axis is not, as desired, orthogonal to elevation axis L. Even with the gun leveled to the horizon, a change of elevation λ results in an error of azimuth α. Perpendicular offset error $\Delta\alpha 2$ may in principle be described and/or appropriately corrected using a function which is essentially proportional to the sum of a tangent function of λ and an inverse cosine function of λ, specifically $\Delta\alpha 2 = a \text{ tg } \alpha + b/\cos \lambda - b$. At an elevation of 90° or nearly 90°, correction may obviously not be performed on the basis of this function, since cos λ is infinite here. Perpendicular offset error $\Delta\alpha 2$ is measured using the first measurement unit of the gyroscopic measurement system.

Preferably and finally, squint error $\Delta\sigma$ is detected in a third measurement procedure. This error represents the non-parallelism of the weapon barrel axis and the line of sight. Squint error $\Delta\sigma$ is established and prepared in the method according to the present invention in a typical way, which is therefore not described in more detail.

Further characteristics and advantages of the present invention are described in the following with reference to examples and in relation to the drawing.

Fig. 1A shows a weapon system having a device according to the present invention in a schematic illustration;

Fig. 1B shows a gun of the weapon system in Fig. 1A in a simplified illustration, with three axes of an orthogonal axis system;

Fig. 2A shows a schematic illustration to explain the azimuth synchronization error;

Fig. 2B shows empirical error curves of the azimuth synchronization error;

Fig. 3A shows empirical error curves of the wobble error,

Fig. 3B shows an empirical error curve of the wobble error; only the error component caused by the lower gun carriage is illustrated;

Fig. 3C shows an empirical error curve of the wobble error; only the error component caused by the leg support is illustrated;

Fig. 4A shows an empirical error curve of the elevation synchronization error for a constant azimuth;

Fig. 4B shows elevation synchronization errors as a function of azimuth with various elevations as a parameter; and

Fig. 5 shows an empirical error curve and a mathematical error function of the perpendicular offset error.

Since detectable errors are known to be small in comparison to the absolute values, for example of azimuth or elevation, diagrams which represent error curves and error functions are not to scale, so that the course of the functions is clearly visible.

Fig. 1A schematically shows a weapon system 10. A weapon system 10 has a gun 10.1 having a weapon barrel 10.2, a fire control device 10.3, and a fire control computer and/or system computer 10.4. A weapon system 10 also has an intended value sensor 10.5, using which the intended position of weapon barrel 10.2 is detected.

Furthermore, Fig. 1A shows a device 20 for performing the method according to the present invention. Device 20 has a measurement facility 20.1 for detecting the actual values, which describe the actual positions of weapon barrel 10.2 after aiming, and a computer unit 20.2. Intended value sensor 10.5 is typically a component of weapon system 10, but its functions may also be included in device 20.

Fig. 1B shows gun 10.1 of weapon system 10, having a lower gun carriage 12, an upper gun carriage 14, and weapon barrel 10.2. Lower gun carriage 12 is supported via three legs 12.1, 12.2, and 12.3 on a horizontal support surface 1. In Fig. 1, the orthogonal axis system of the three axes is also shown, the vertical axis being indicated with A, the lateral axis with L, and the longitudinal axis with R. Weapon barrel 10.2 may be rotated around vertical axis A to change the lateral angle and/or azimuth α and may be rotated around lateral axis L to change the vertical angle and/or elevation λ.

An optical-electronic gyroscopic measurement system 22, which forms a component of measurement facility 20.1, is positioned on weapon barrel 10.2 in the muzzle region. A gyroscopic measurement system 22 includes a first measurement unit and/or α-measurement unit and a second measurement unit and/or λ-measurement unit, using which angle changes resulting from changed azimuth α and/or changed elevation λ of weapon barrel 10.2 may be detected.

In the following, the procedure for compensating an azimuth synchronization error $\Delta\alpha 1$ and for compensating a wobble error $\Delta\tau$, which are detectable within a first measurement procedure, but in separate partial procedures, are described.

Figs. 2A to 2C relate to the partial procedure concerning azimuth synchronization error $\Delta\alpha 1$. In Fig. 2A, gun 10.1 is illustrated greatly simplified in a top view. Weapon barrel 10.2, illustrated in simplified form as a weapon barrel axis, is indicated with solid lines in its zero position and with dashed lines in one of the measurement positions, which, with the zero position, encloses an angle of, for example, 20°. Starting from the zero position, weapon barrel 10.2 is rotated a total of 180° into a final position in steps of, for example, 5° in the direction of arrow D1. The rotation of weapon barrel 10.2 is controlled by fire control computer 10.4. Each measurement position is determined by the associated lateral angle and/or associated azimuth α. After each step, weapon barrel 10.2 is theoretically in an intended position, which is defined by the associated intended value and/or an associated intended azimuth $\alpha 1$(theor), which is displayed, for example, on gun 10.1. In reality, weapon barrel 10.2 is, however, in an actual position, which is indicated by an actual value and/or an actual azimuth $\alpha 1$(eff) detected by the α-measurement unit of gyroscopic measurement system 22 of measurement facility 20.1. Computer unit 20.2 computes the error value and/or the error angle in each case, i.e., the deviation of actual value $\alpha 1$(eff) from intended value $\alpha 1$(theor). The error values are then illustrated, as a function of $\alpha 1$(theor), as first-directional empirical azimuth error curve $f\alpha 1(D1)_1$. The method steps described up to this point are repeated multiple times in order to remove random errors in the detection of actual azimuth and intended azimuth as much as possible. In this way, further first-directional empirical azimuth error curves $f\alpha 1(D1)_2$, $f\alpha 1(D1)_3$, $f\alpha 1(D1)_i$ are established. As shown in Fig. 2B, an average first-directional azimuth error curve $f\alpha 1$(D1) finally results from all of the first-directional azimuth error curves. Subsequently, the method steps described above are performed again, weapon barrel 10.2 being rotated in the opposite direction, i.e., in the direction of arrow D2. Multiple second-directional azimuth error curves $f\alpha 1(D2)_1$, $f\alpha 1(D2)_2$, $f\alpha 1(D2)_3$ and an average second-directional empirical azimuth error curve $f\alpha 1$(D2) result from this, also shown in Fig. 2B. Next, an average direction-free empirical azimuth error curve fα1(D0) , which is also shown in Fig. 2B, is calculated from average first-directional empirical azimuth error curve fα1(D1) and average second-directional empirical azimuth error curve fα1(D2). As shown in Fig. 2B, average direction-free azimuth error curve fα1(D0), which describes azimuth synchronization error Δα1, runs approximately in the shape of a sine curve having a double angular frequency. This indicates that there is a slight ovality in the lateral pivot bearing.

In the numerical methods, average direction-free empirical azimuth error curve fα1(D0) and/or the value pairs which define this curve are made available to the fire control computer and/or system computer, in order to make them available during further calculations of aiming values. The numerical methods may be performed analogously for all measurement procedures.

In the mathematical methods, average direction-free empirical azimuth error curve fα1(D0) is approximated by a mathematical azimuth error function Fα1. The approximation is performed either by a mathematical partial error function for each section, the totality of the partial error functions being referred to as the mathematical error function, or as a whole by one single mathematical error function. Mathematical error function Fα1 is used to produce a correction function, which is taken into consideration during calculation of the aiming values, together with other available data. To check, after the implementation of the correction function in the software of system computer 10.4, the method steps described up to this point may be performed again; corrected azimuth error curve $f\alpha1(D0)_{korr}$ established in this way runs significantly flatter than non-corrected error curve fα1(D0); the original observable azimuth synchronization error therefore may be reduced to a very small residual error and/or may be compensated almost completely.

The method steps described above may be performed partially in other sequences, which influences the results insignificantly or not at all. In particular, it is time-saving to perform the measurements to establish the first-directional error function and the second-directional error function alternately.

In order to achieve more precise results, establishing direction-free azimuth error curve fα1(D0) may be dispensed with; in place of this mathematical azimuth error functions Fα1(D1) and Fα1(D2) are determined for first-directional empirical azimuth error curve fα1(D1) and second-directional empirical azimuth error curve fα1(D2), respectively, and the corresponding correction functions are determined therefrom.

Figs. 3A to 3C relate to wobble error Δτ. Weapon barrel 10.2 is theoretically to be directed horizontally at an elevation of 0°, i.e., the intended elevation must be 0°. In reality, weapon barrel 10.2 will always have a slight inclination to the horizontal, i.e., the actual elevation is not 0°, but differs from 0° by Δτ. Angle Δτ is a function of azimuth α. During a rotation through 360° around vertical axis A, weapon barrel 10.2 therefore performs a wobble motion, which is described by a wobble error function. To detect wobble error Δτ, weapon barrel 10.2 is moved without elevation λ in the same steps as for establishing azimuth synchronization error Δα1. However, the effective inclination and/or wobble angle of weapon barrel 10.2 is detected after each measurement step, which is referred to as weapon barrel wobble angle τ(eff). The theoretical inclination and/or wobble angle, which is referred to as intended value and/or intended wobble angle τ(theor), is zero. Actual value and/or actual wobble angle τ(eff) may be represented in a function of azimuth α(theor). Now, an average first directional and an average second directional empirical wobble error curve fτ(D1) and fτ(D2), respectively, are determined analogously to the establishment of average empirical azimuth error curve fα(D1) and fα(D2). Finally, a direction-free empirical wobble error curve fτ(D0) results therefrom, which is approximated by a mathematical wobble error function Fτ. In Fig. 3A, the two extreme wobble error curves of multiple established empirical wobble error curves are illustrated, between which all other wobble error curves lie; the measurements appear to be quite precise, since the curves only deviate slightly from one another; the wobble movement is a sinusoidal movement. An analysis of the measurement data for the wobble movement provides results which are illustrated in Figs. 3B and 3C. As a consequence, the wobble error has two causes: firstly, the azimuth-dependent rigidity of the lower gun carriage; the component of the wobble error resulting therefrom is illustrated in Fig. 3B; secondly, the stiffening effect due to the legs, also azimuth-dependent, this component of the wobble error being illustrated in Fig. 3C. In Figs. 3B and 3C, the positive values of the wobble error are illustrated using solid lines and the negative values of the wobble error are illustrated using dashed lines.

Next, the compensation of elevation synchronization error $\Delta\lambda$, which is detected in a second measurement procedure, will be described. Elevation synchronization error $\Delta\lambda$ comprises two error components. Both error components are detectable using a second measurement unit and/or λ-measurement unit of gyroscopic measurement system 22 of measurement facility 20.1, and only as their sum. Therefore, λ refers to and/or indexes data and/or functions which relate to total elevation synchronization error $\Delta\lambda$. In this case, elevation λ is understood to be the angle of inclination of weapon barrel 10.2 to the horizontal assumed by weapon barrel 10.2 while keeping azimuth α constant. Elevation λ, starting from a horizontal position, i.e., from an elevation of 0° and also a perpendicular deviation of 0°, is changed in steps of, for example, 5° up to a final position of, for example, 85°. The movement of weapon barrel 10.2 is controlled by computer. After each step, weapon barrel 10.2 is in a measurement position. In this case, its elevation is theoretically a value which is referred to as an intended value and/or intended elevation λ(theor) and which is indicated by intended value sensor 10.5. However, weapon barrel 10.2 is in another position, which is described by actual value and/or actual elevation λ(eff). As described above in regard to the azimuth synchronization error, the difference between the λ(theor) and λ(eff) is represented in a function of λ(theor). The movement of weapon barrel 10.2 is repeated multiple times in both rotational directions. An average first-directional empirical elevation error curve $f\lambda(D1)$ and an average second-directional empirical elevation curve $f\lambda(D2)$ is obtained from the measurement results recorded in this case. A direction-free elevation error curve $f\lambda(D0)$ results therefrom, which is shown in Fig. 4A with a solid line. It may be seen in Fig. 4A that with increasing elevation λ, i.e., with continuously steeper positioning of weapon barrel 10.2, elevation error curve fλ(D0) rises. Empirical elevation error curve fλ(D0) is then approximated by a mathematical elevation error function Fλ, and a correction function is determined which is taken into consideration in the calculation of the aiming values. If the measurements are repeated, but taking the correction functions into consideration, the corrected elevation error function runs much more flatly than the uncorrected one.

The error components of elevation synchronization error Δλ which may not be individually detected during the measurement may be established using a mathematical analysis of mathematical elevation error function Fλ.

The first error component of the elevation synchronization error would, by itself, result in an error function which essentially corresponds to a sine function having multiple angular frequencies.

By itself, the second error component of the elevation synchronization error would result in an error function $f\lambda(D0)_2$, which essentially follows a cosine function subtracted from 1, illustrated in Fig. 4A using a dashed line. This corresponds to the fact that, with increasing elevation, the torque exercised by the weight of weapon barrel 10.2 on the gun carriage is reduced, because the distance of the line of application of the weight of weapon barrel 10.2 from lateral axis L is reduced; this torque tends to tilt gun 10.1 and therefore weapon barrel 10.2 forward; a reduction of this torque consequently has the effect that gun 10.1 having weapon barrel 10.2 tilts forward less and/or relatively tilts backward.

The sum of the error components corresponds to elevation error curve fλ(D0), resulting from the measurements performed. This is represented as an oscillation corresponding to the first error component around a rising curve corresponding to the second component.

The measurements described above of elevation synchronization error Δλ of the second measurement are performed with azimuth α kept constant. Multiple further measurement series are then performed for further azimuths, with the azimuth kept constant in each measurement series, the angular intervals between the fixed azimuths able to be, for example, 5°. In this case as well, two measurement series are preferably performed for azimuth, rotation being in a first rotational direction for the first measurement series and in the opposite rotational direction for the second measurement series. Fig. 4B shows a spatial parameter illustration of elevation synchronization error Δλ as a function of azimuth α, using various elevations λ as a parameter, the bottom curve corresponding to the smallest elevation.

The further steps for compensating the elevation synchronization error are performed analogously to the compensation of the azimuth synchronization error described above.

It is also to be noted that, as described above in regard to the compensation of the azimuth synchronization error, the individual measurement and analysis procedures may be performed at least partially in different sequences, without influencing the results.

Perpendicular offset error Δα2 is also established within the second measurement procedure. For this purpose, in each of the measurement positions in which, with the aid of the λ measurement unit, elevation synchronization error Δλ is determined, perpendicular offset error Δα2 is determined with the aid of the α-measurement unit. Fig. 5 shows the perpendicular offset error as a function of elevation λ. Empirical perpendicular offset error curve fα2, shown with a dashed line, may be approximated by a mathematical perpendicular offset error function Fα2, shown with a solid line, for example by a second order polynomial.

The detection and the compensation of perpendicular offset error Δα2 is performed analogously to the compensation of azimuth synchronization error Δα1 described above.

Finally, a third measurement procedure is performed, with the aid of which a compensation of squint error $\Delta\sigma$ is performed. Squint error $\Delta\sigma$ arises because the directions of the weapon barrel axis and the line of vision of the gun are not coincidental, but rather enclose a squint angle. To establish the squint error, the extensions of the weapon barrel axis and the line of vision are displayed at a certain distance to the muzzle of the weapon barrel, for example using a projection, the weapon barrel axis and the line of vision appearing as points. The deviation of the two points is a measure of the squint error, the distance between the weapon barrel and the projection surface also having to be considered to establish this error. This method of establishing the squint error is not novel and is only described here for supplementary purposes, since complete compensation of firing errors which are caused by static gun geometry errors must also take squint error into consideration.

While the description above predominantly relates to the method according to the present invention, in the following, the device used to perform this method is described in more detail.

It is noted here again that the novel method is performed using the novel device on a weapon system 10 as shown in Fig. 1A. Weapon system 10 has gun 10.1 having at least one weapon barrel 10.2, whose movements are controlled in a typical way using gun servomotors. Furthermore, weapon system 10 has fire control device 10.3. Weapon system 10 also has system computer and/or fire control computer 10.4, which is positioned on fire control device 10.3 or, at least partially, on gun 10.1. Weapon system 10 typically also has an intended value sensor 10.5, which indicates the intended values, particularly of azimuth α and elevation λ, which describe the intended position of aimed weapon barrel 10.2 determined by system computer 10.4.

Multiple components are necessary to perform the novel method, which are described in more detail in the following:

A first component is formed by intended value sensor 10.5, which is used for the purpose of indicating the intended values, which describe the intended and/or supposed position of weapon barrel 10.2. The intended value sensor present on weapon system 10 in any case is used as the intended value sensor.

A second component of the novel device is formed by measurement facility 20.1, for detecting the actual values, which describe the actual position of weapon barrel 10.2. Measurement facility 20.1 includes at least optical-electronic gyroscopic measurement system 22.1, for example a fiber-optic measurement system. Gyroscopic measurement system 22.1 has at least a first and/or α-measurement unit for detecting changes of angle, preferably of azimuth α, of weapon barrel 10.2. Preferably, gyroscopic measurement system 22.1 also has a second and/or λ-measurement unit for detecting changes of elevation λ of weapon barrel 10.2.

In the framework of the present invention, optical-electronic gyroscopic measurement systems are to be understood to include not only fiber-optic measurement systems, but also other measurement systems, for example ring laser gyroscopic measurement systems. Gyroscopic measurement systems generally have the advantage that they operate autonomously; therefore, no reference points external to the system have to be used. Guns do not have to be brought into a separate measurement station. However, because there is no reference external to the system, the system generally drifts over time. The gyroscopic drift manifesting in this case must be determined and taken into consideration during the analysis of the measurement results. A laser positioning system may be used in connection with this.

In order to detect the static gun geometry errors more completely and therefore to perform a more precise compensation of firing errors caused by them, the second component of the novel device, i.e. measurement facility 20.1, preferably also has measurement systems for detecting further errors, particularly wobble error $\Delta\tau$ and squint error $\Delta\sigma$.

In order to detect wobble error Δ_T, in addition to gyroscopic measurement system 22.1, a further measurement system 21.2 in the form of a typical, preferably electronic, spirit level is used. This level measures angles in relation to the horizontal, in the present exemplary embodiment, the respective angle of the weapon barrel axis to the horizontal. An electronic spirit level is understood as a sensor which measures the horizontal angle, i.e., the angle to a horizontal, and outputs an electric signal correlated to this angle. The measurement uses effects of gravitation, which define the vertical and therefore also the horizontal. In this case, it is unimportant how the sensor uses gravitation.

It is also noted here that the tilt of gun 10.1 may be determined with the aid of an electronic spirit level. Tilt is understood as the following: if weapon barrel 10.2 is only moved in the azimuth, then the movement of the muzzle of the weapon barrel may be approximately considered as a circular line which defines a plane. The angular deviation of this plane in relation to the horizontal plane is referred to as tilt; in other words, without tilt, this plane would be a horizontal plane. Generally, in new guns, the tilt is automatically compensated and/or the gun is automatically leveled to the horizontal. The leveling to the horizontal of the gun is, however, not necessary for performing the novel method.

In order to detect squint error Δ_T, in addition to gyroscopic measurement system 22.1 and electronic spirit level 22.2, a further measurement system 22.3 in the form of a typical, preferably optical, device is used. This device measures the angular difference between the weapon barrel axis and the line of vision of gun 10.1.

A computer is required as a third component for performing the novel method. The computer is implemented, as shown in Fig. 1A, as a separate computer unit 20.2, which is used exclusively to perform the novel method or also for other purposes and is only coupled to the weapon system 10 for this purpose. However, fire control computer and/or system computer 10.4 of weapon system 10 may also possibly be used as the computer.

The third component of the novel device, in the present case computer unit 20.2, has a data input and/or a data interface, via which it is supplied at least data which represent the detected intended values and actual values. The data may be made available to computer unit 20.2 in any desired suitable way, for example with the aid of a data carrier such as a diskette, or via a data circuit, which may be material or immaterial.

If fire control computer and/or system computer 10.4 is used as the computer, then it already knows the intended values and the actual values are made available to it via a data input and/or a data interface 24.

The third component of the novel device, in the present case computer unit 20.2, further has software implemented in order to determine the correction values from the intended values and the actual values. The steps to be performed in this case are described in more detail above in relation to the method according to the present invention.

If fire control computer and/or system computer 10.4 is used as the computer, the correction values established may be implemented directly in the fire control software.

If the fire control computer and/or system computer is not used as the computer, but rather separate computer unit 20.2, the established correction values must be made available to fire control computer and/or system computer 10.4 via data input and/or data interface 24 and implemented in the fire control software on the computer.

The third component, i.e., the computer, preferably has an input unit 20.3, such as a keyboard, via which further data may be made available, particularly if it is formed by separate computer unit 20.2. This may include, for example, data which controls the progress of the novel method, in that it, among other things, controls the step-by-step rotation of the weapon barrel into the measurement positions by the servomotors and the coupling of the respective measurement systems and/or measurement units to be used.

WHAT IS CLAIMED IS:

1. A method for compensating firing errors of a gun having a weapon barrel (10.2), caused by static gun geometry errors, which influence the position of the weapon barrel (10.2) during aiming of the weapon barrel (10.2) at aiming values,

- the weapon barrel (10.2) is brought into measurement positions in steps by rotation around an axis (A, L),
- at each measurement position
    - an intended value, which describes the intended position of the weapon barrel (10.2), and
    - an actual value, which describes the actual position of the weapon barrel (10.2), are detected,
    - a difference between the actual value and the intended value, defined as an error value, is calculated,
- correction values are established from multiple error values and
- the correction values are taken into consideration during later aiming of the weapon barrel (10.2).

2. The method according to claim 1, characterized in that, to establish the correction values,

- the correction values are represented empirically,
- the empirically represented error values are approximated by a mathematical error function, and
- the correction values, which are taken into consideration during a later calculation of the aiming values for the weapon barrel (10.2), are determined from the mathematical error function.

3. The method according to claim 2, characterized in that the correction values are determined in the form of a correction function.

4. The method according to any one of claims 1 to 3, characterized in that a measurement facility (20.1), which has an optical-electronic gyroscopic measurement system (22.1) having a first measurement unit, using which the azimuth synchronization error ($\Delta\alpha 1$) and/or perpendicular offset error ($\Delta\alpha 2$) is/are detected, is used for detecting the actual values.

5. The method according to any one of claims 1 to 4, characterized in that a measurement facility (20.1), which has an optical-electronic gyroscopic measurement system (22.1), having a second measurement unit, using which the elevation synchronization error ($\Delta\lambda$) is detected, is used for detecting the actual values.

6. The method according to any one of claims 1 to 5, characterized in that a measurement facility (20.1), which has a measurement system (22.2) having a spirit level, using which the wobble error ($\Delta\tau$) is detected, is used for detecting the actual values.

7. The method according to claim 6, characterized in that said spirit level is an electronic spirit level.

8. The method according to any one of claims 1 to 7, characterized in that a measurement facility (20.1), which has a measurement system (22.3) having a device, using which the squint error ($\Delta\sigma$) is detected, is used for detecting the actual values.

9. The method according to any one of claims 1 to 8, characterized in that the intended values and the actual values are made available to a computer (20.2, 10.4), which determines the correction values and/or the correction function.

10. The method according to any one of claims 1 to 9, characterized in that the correction values are stored in a system computer (10.4) assigned to the gun (10.1), in order to be used during the calculation of the aiming values for aiming the weapon barrel (10.2).

11. The method according to any one of claims 1 to 10, characterized in that the weapon barrel (10.2), during its rotation into the measurement positions, is rotated around the vertical axis (A) of the gun (10.1) and preferably also around the lateral axis (L) of the gun (10.1).

12. The method according to claim 4 or 5, characterized in that, during detection of the actual values with the aid of an optical-electronic gyroscopic measurement system (22), a gyroscopic drift of the gyroscopic measurement system (22) is determined at temporal intervals or continuously and taken into consideration in the actual values detected.

13. A device for compensating firing errors of a gun having a weapon barrel (10.2), these firing errors being caused by static gun geometry errors, which influence the position of the weapon barrel (10.2) during aiming of the weapon barrel (10.2) at calculated aiming values, this device having a measurement facility (20.1) for establishing actual values, which describes the position of the weapon barrel, the measurement facility (20.1) having an optical-electronic gyroscopic measurement system (22.1) on the weapon barrel (10.2), having a first measurement unit, in order to detect azimuth synchronization error ($\Delta\alpha 1$) and possibly perpendicular offset error ($\Delta\alpha 2$).

14. The device according to claim 13, characterized in that the optical-electronic gyroscopic measurement system (22.1) has a second measurement unit in order to detect elevation synchronization error ($\Delta\lambda$).

15. The device according to claim 13 or 14, characterized in that the measurement facility (20.1) has

- a measurement system (22.2) having a spirit level in order to detect wobble error ($\Delta\tau$), and/or
- has a measurement system (22.3) having a device in order to detect squint error ($\Delta\sigma$).

16. The device according to claim 15, characterized in that said spirit level is an electronic spirit level and/or said device to detect squint error ($\Delta\sigma$) is an optical device.

17. The device according to any one of claims 13 to 16, characterized in that:

- it has a computer unit (20.2), connected on an input side:
  - to an intended value sensor (10.5), which makes intended values available which describe the intended position of the weapon barrel (10.2), and
  - to the measurement facility (20.1), which makes the actual values available,
- said computer unit (20.2) calculating:
  - correction values on the basis of the intended values and actual values,
  - aiming values for the weapon barrel (10.2), taking into consideration said correction values, in order to compensate the firing errors, and
- said computer unit being connected on the output side to a system computer (10.4), in order to make data which represent the correction values available thereto.

18. The device according to claim 17, characterized in that the computer unit (20.2) has an input unit (20.3) for inputting data.

19. A system computer (10.4) of a weapon system (10) for calculating aiming values for aiming a weapon barrel (10.2) of a gun (10.1) of the weapon system (10), characterized in that:

- the system computer (10.4) has a data input (24) for data representing correction values,
- the system computer (10.4) calculates aiming values, based on said data representing correction values, compensating aiming errors caused by static gun geometry error which influence the position of the weapon barrel (10.2).

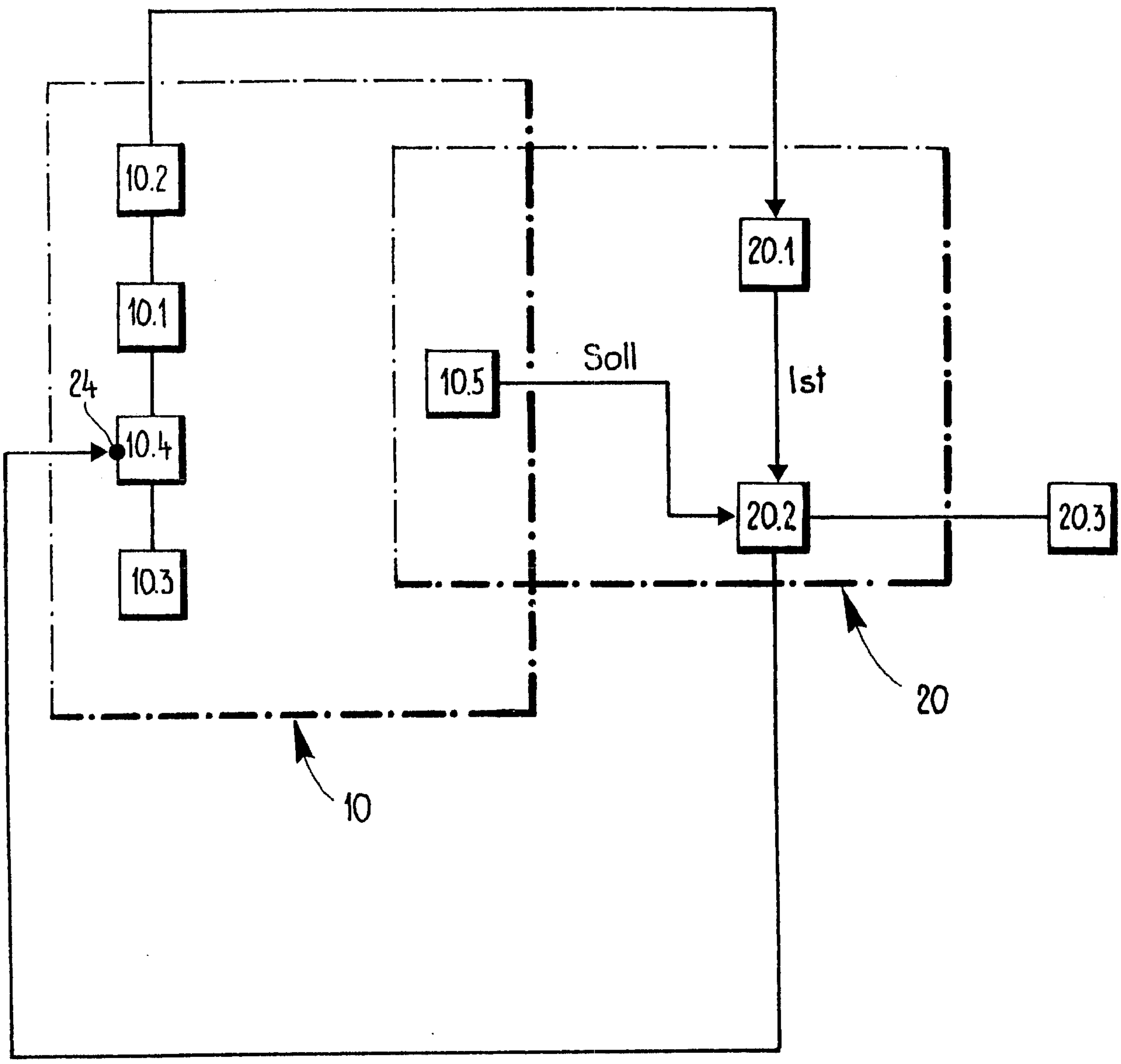


Fig. 1A

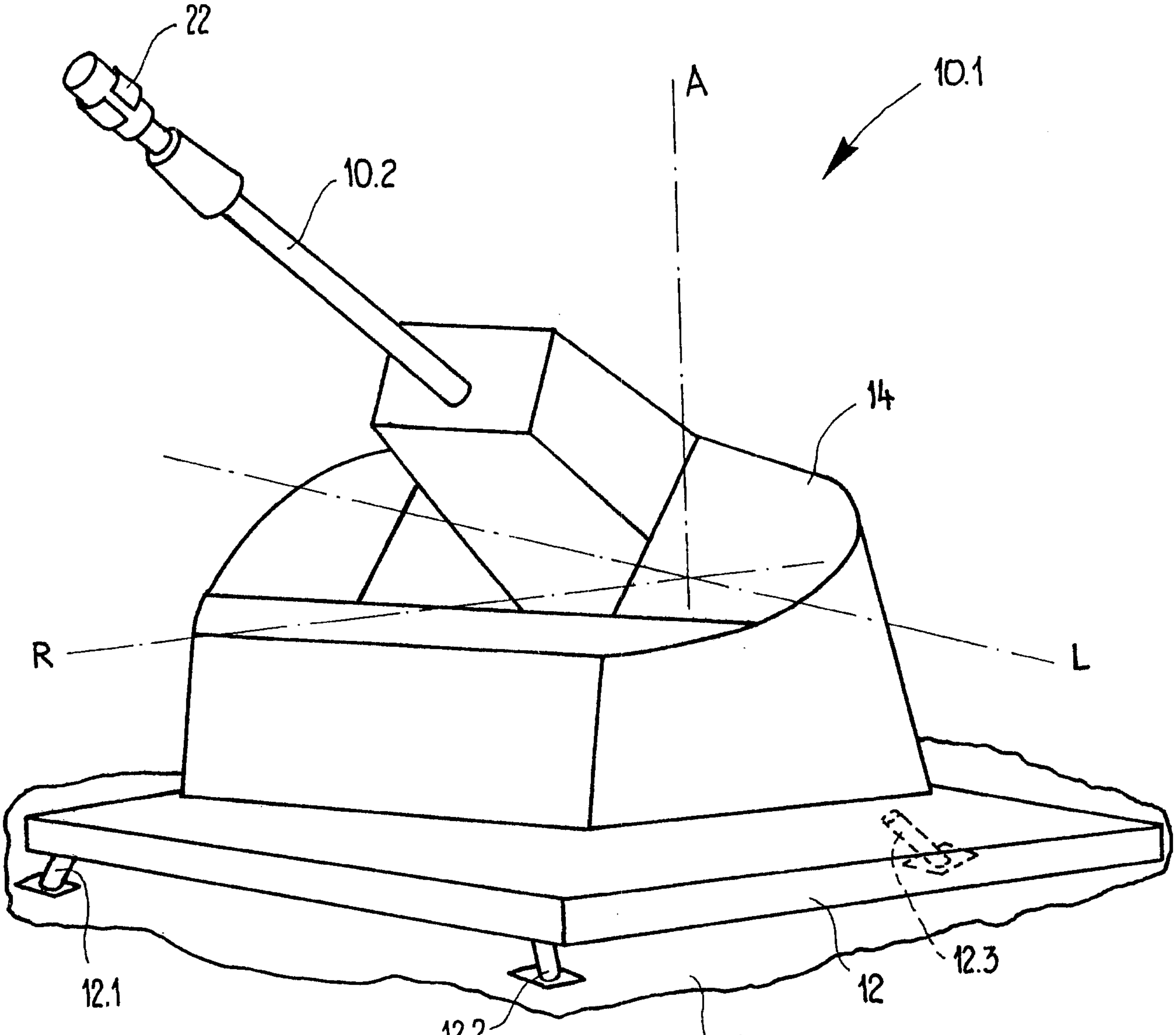


Fig.1B

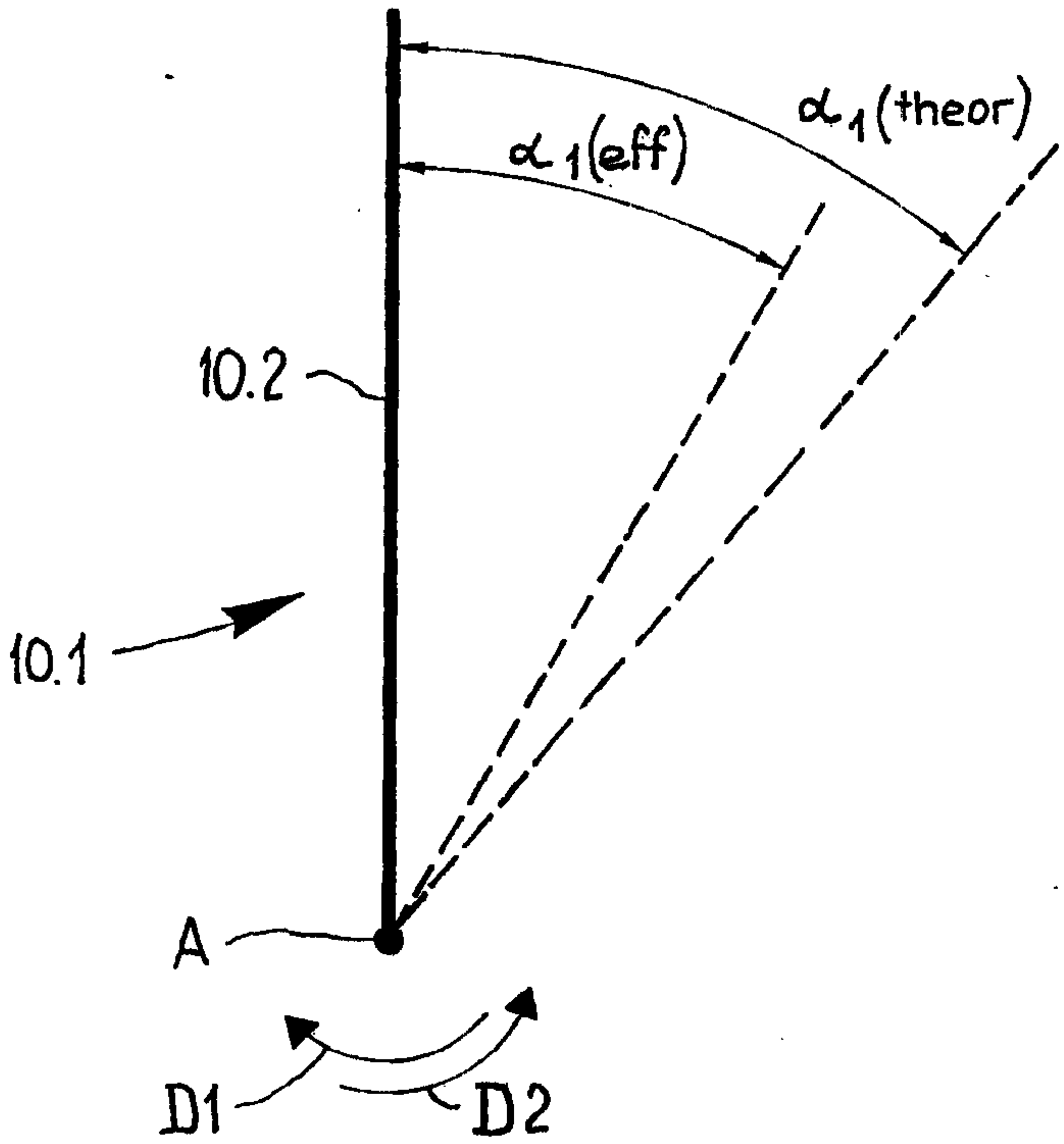

α1(theor)
α1(eff)
10.2
10.1
A
D1
D2

Fig.2A

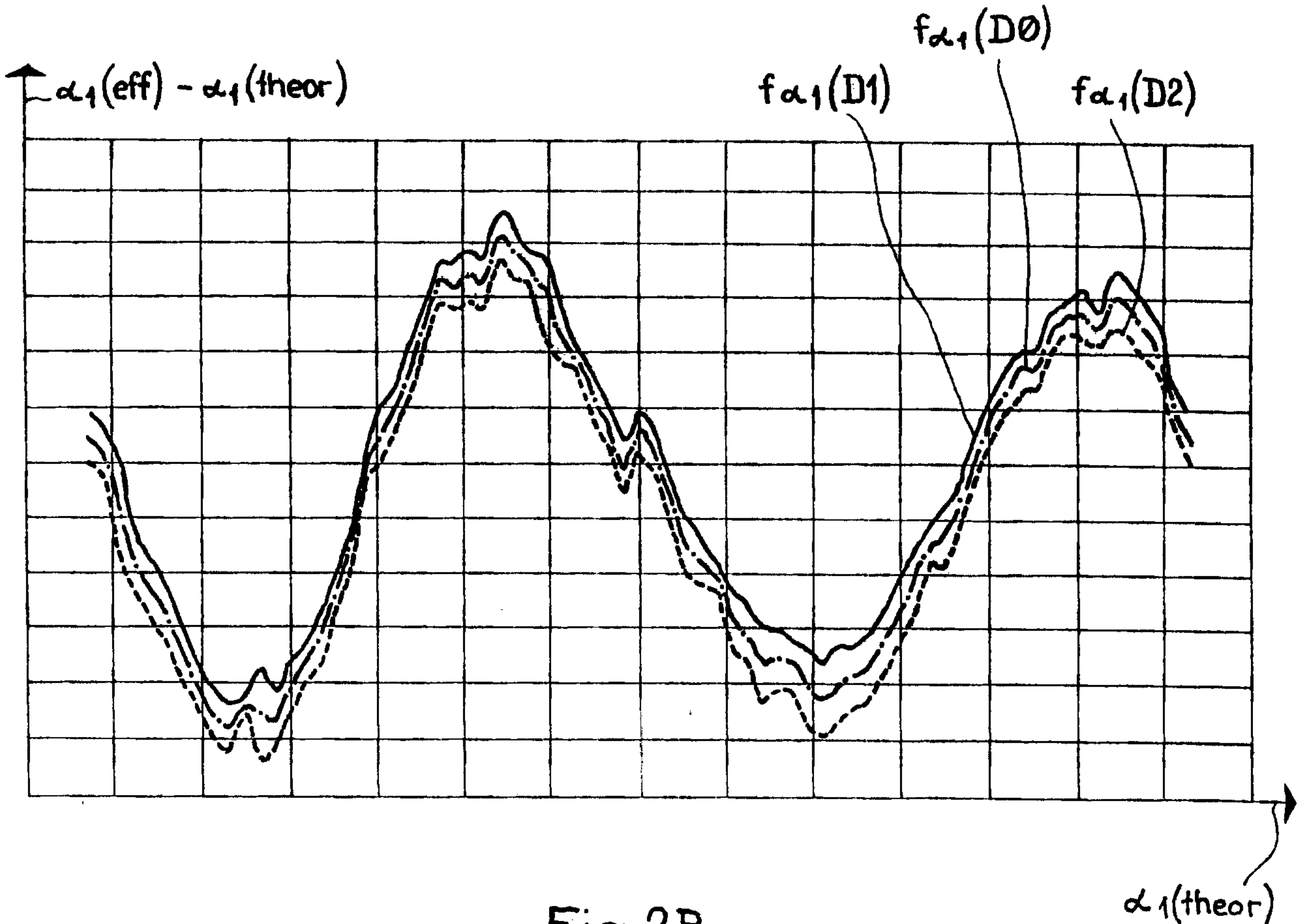

α1(eff) - α1(theor)
fα1(D0)
fα1(D1)
fα1(D2)
α1(theor)

Fig.2B

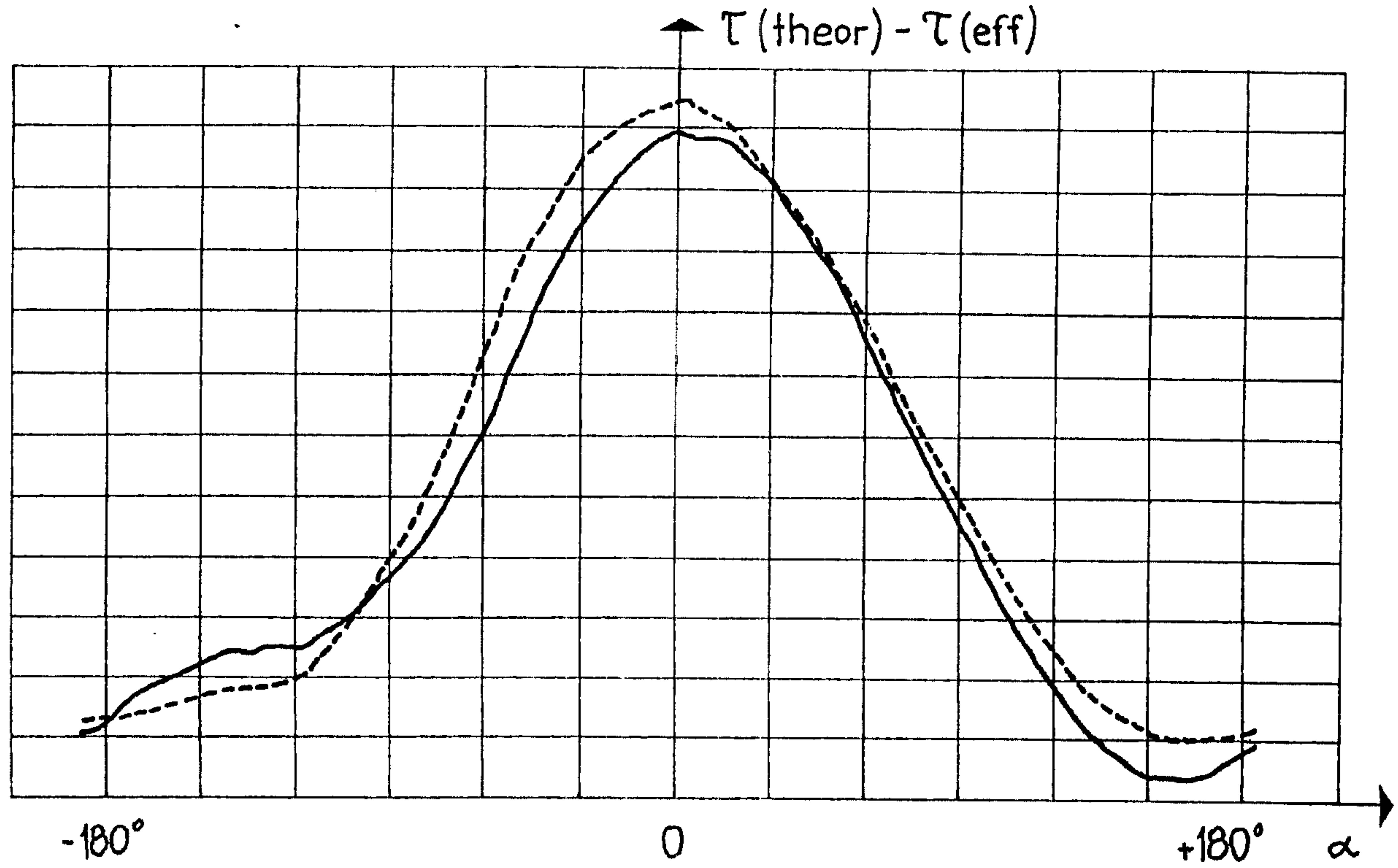


Fig.3A

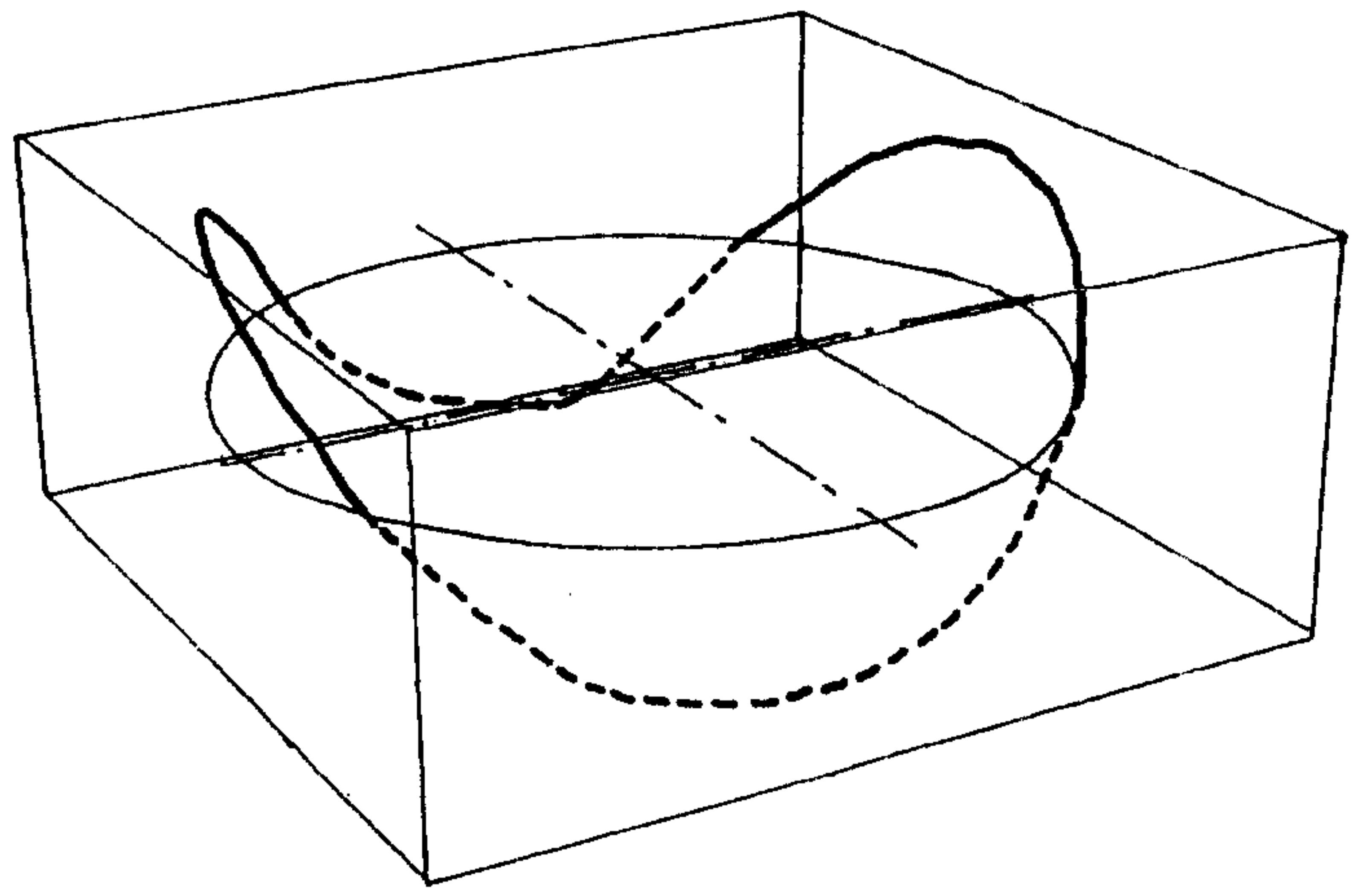


Fig.3B

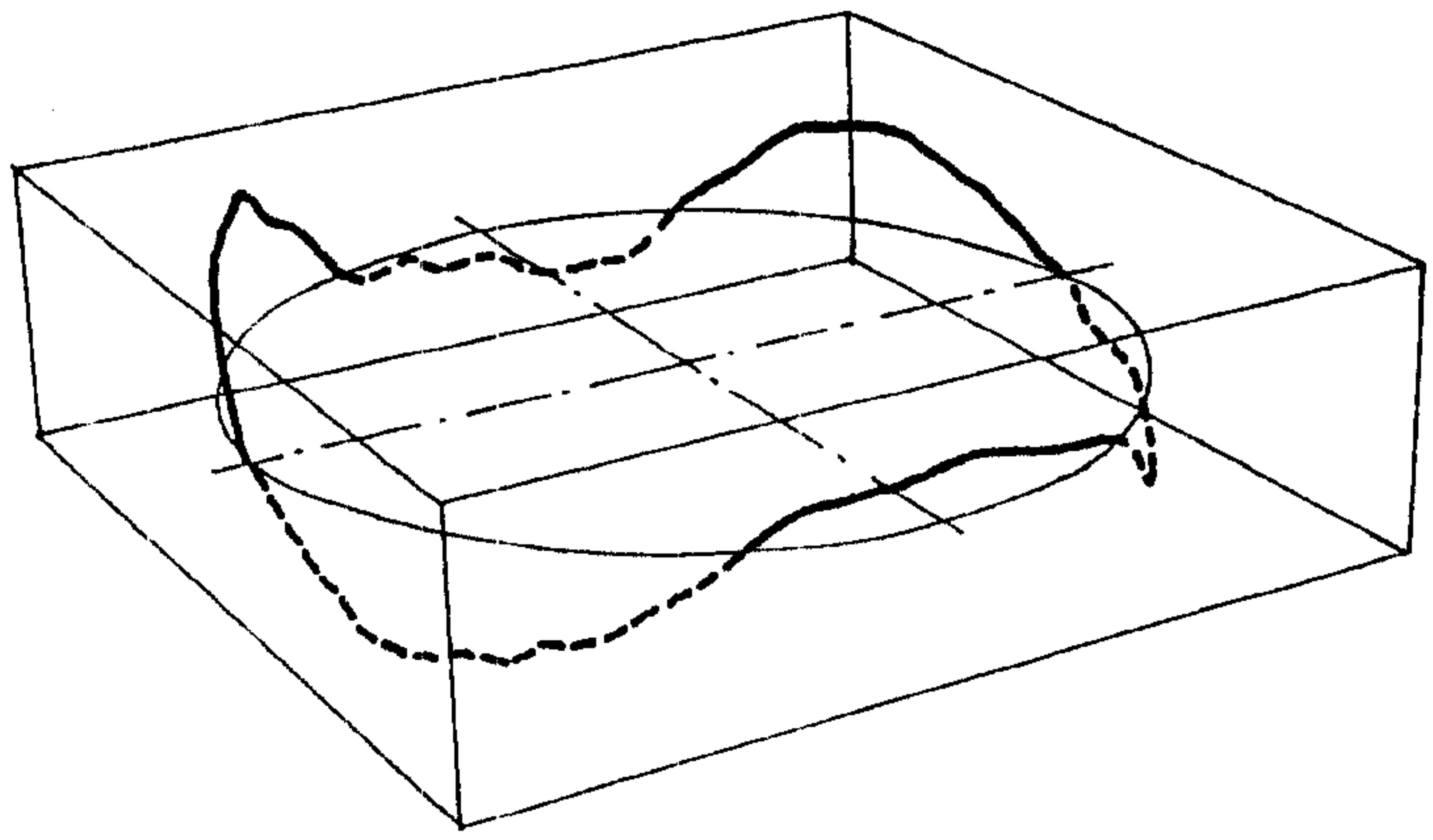


Fig.3C

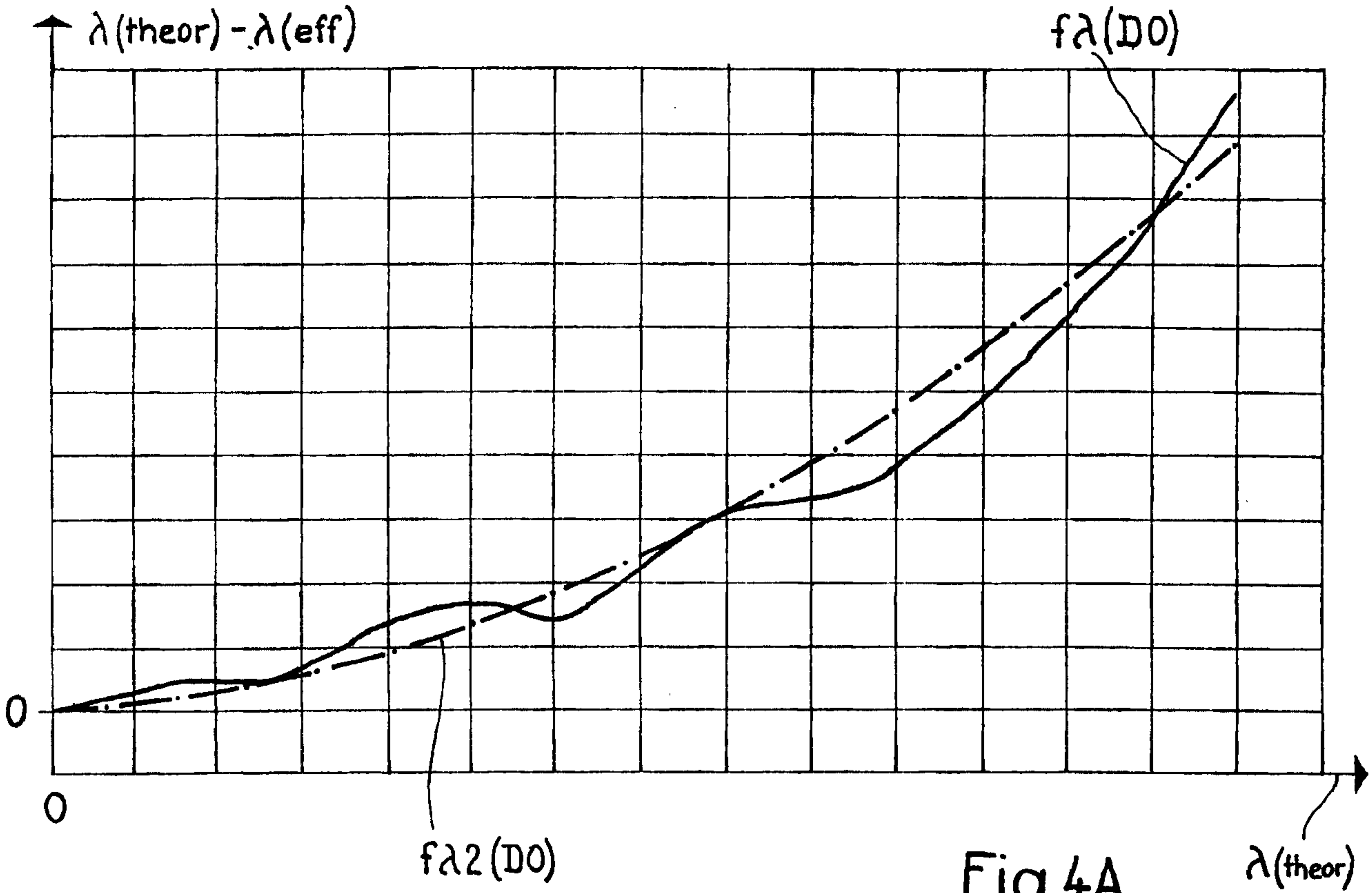


Fig.4A

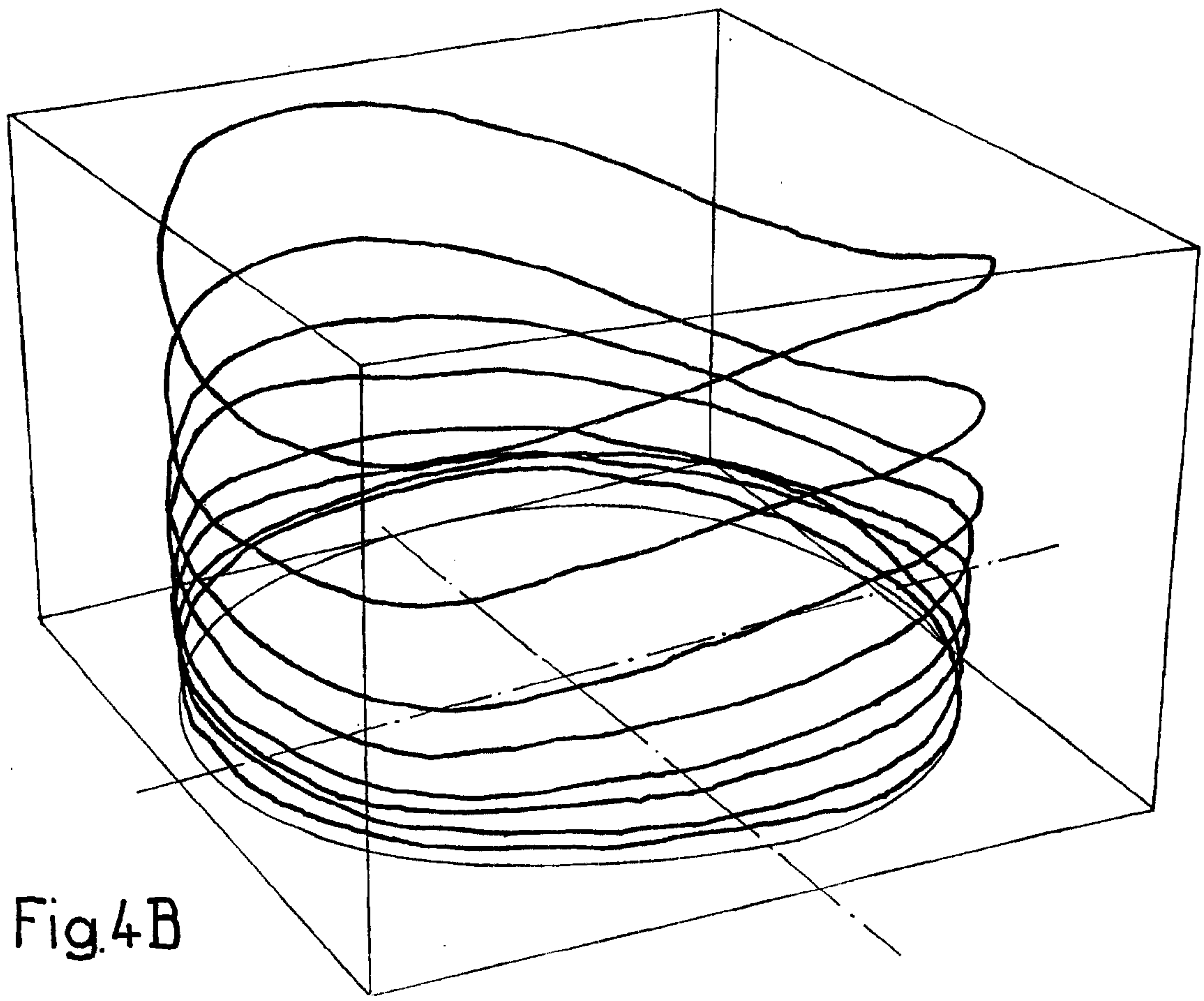


Fig.4B

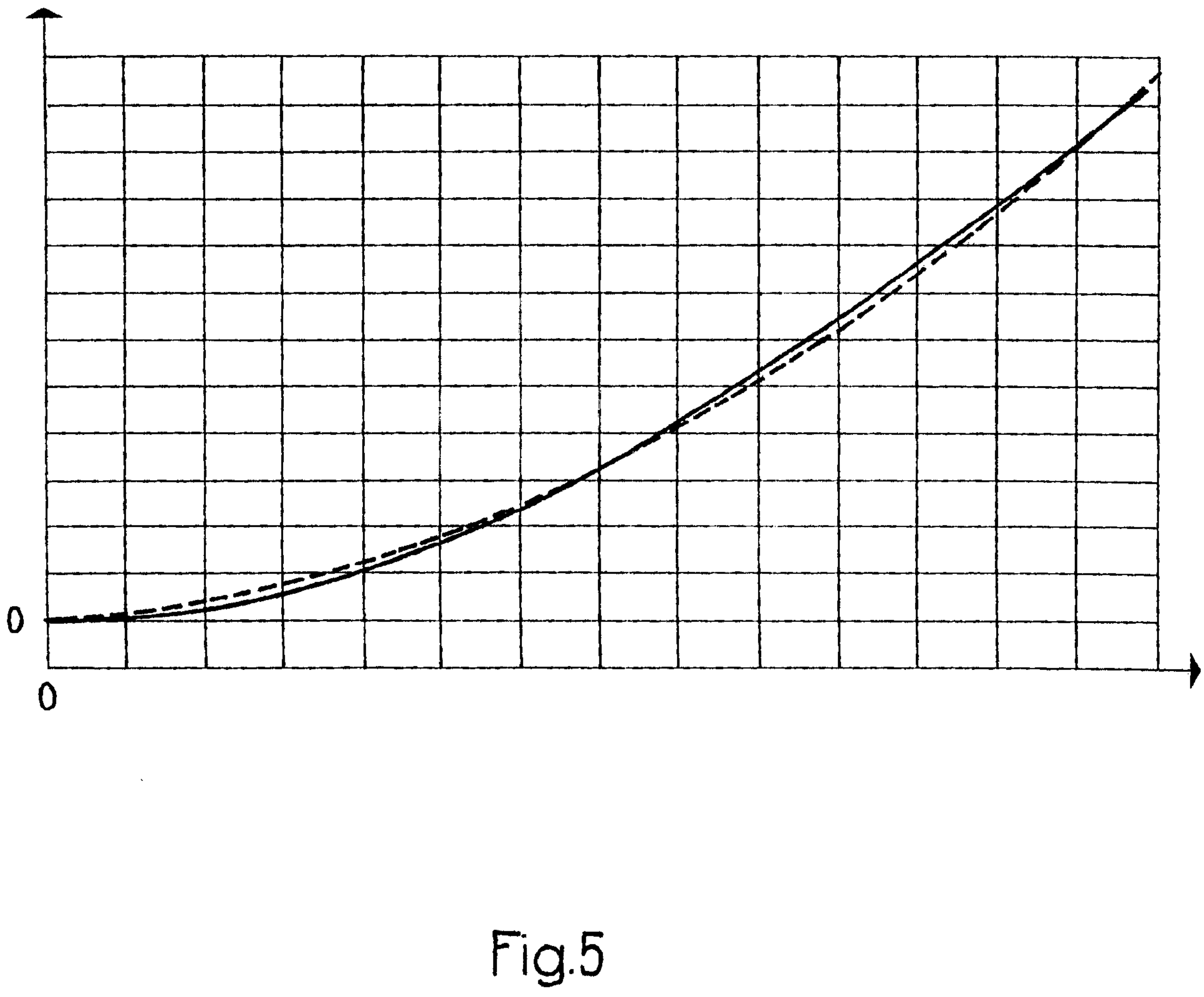
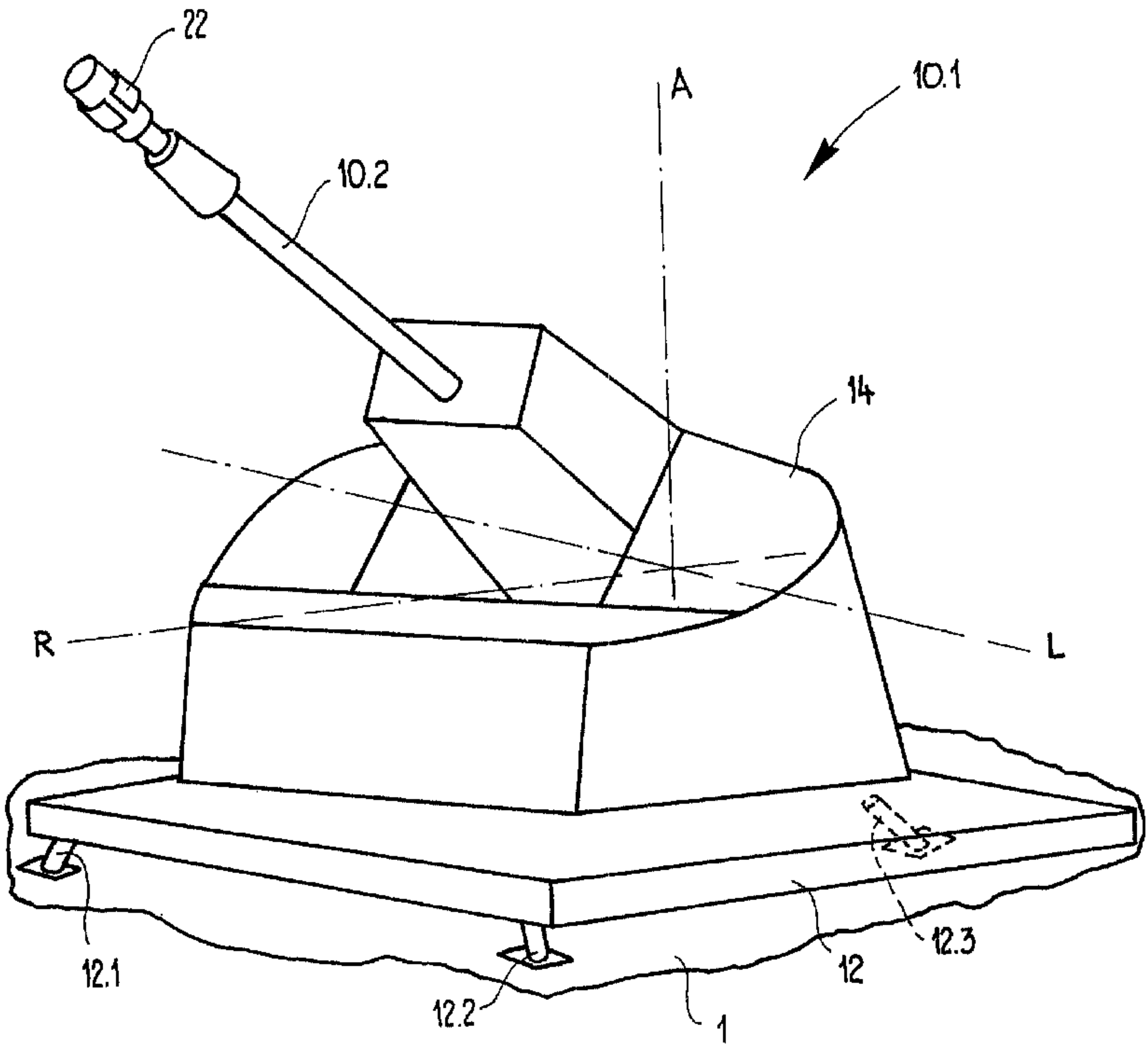


Fig.5


22
A
10.1
10.2
14
R
L
12.1
12.2
1
12
12.3